Time-varying co-movement of the prices of three metals and oil: Evidence from recursive cointegration

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ABSTRACT

The aim of this paper is to study the continuous and time-varing long-run relationships among three metals' prices, oil price, and the US dollar exchange rate. The recursive cointegration is applied to trace the dynamic linkages. The empirical evidence is follows. First, the results of the recursive trace statistics display one significant and strong conitegration among the gold price and the other variables over much of the period after 1995, and that the European sovereign debt crisis caused a closer linkage from 2010 to 2012. Second, rising gold prices increase silver and copper prices in the long run and are also a long-run leading indicator of silver and copper prices, but their function as a leading signal becomes unstable and weaker after the 2008-2009 global financial crisis. Finally, the long-run relationship between oil and gold prices is an inverse interaction before 2003, but then turns uncertain after 2003, and there is no long-run causality between the two prices.

Keyword: gold price, oil price, metal prices, recursive cointegration, structural break

1. Introduction

Investors, traders, policy-makers, and producers have been heavily interested in the metals markets in recent decades. There are many reasons, other than changes in supply and economic use, to cause price fluctuations in these markets. One reason is more diversified uses of metals in industries, such as jewelry, photography, medical field, and automobiles, which affect price fluctuations in their markets. Another reason is that new financial innovations, for example, futures, options, and ETFs (exchange-traded funds), can change metal prices. Moreover, price fluctuations of metal markets are usually affected by speculative trades, particularly as greater speculative activities in emerging countries have recently brought more risks into these markets.

Among the major metal markets of gold, silver, and copper, increasing gold prices often cause relative adjustments in other metal prices. Gold and silver are extensively applied to produce jewelry and are also traded for investment, with the characteristic of silver being higher commodity-driven than gold, because its monetary function has gradually decreased. Some empirical works show that gold and industrial metals, such as copper, react differently to economic shocks (Erb and Harvey, 2006; Roache and Rossi, 2010; Elder et al. 2012). Do industrial copper prices show a positive or negative interaction with gold? This paper looks to find the answer to this questions.

The relationships among gold, silver, and copper have also been accompanied by a seemingly similar and associated linkage with the oil market. Oil and these metals are priced in US dollars and are included in the commodity portfolios of investors. The relationships between oil and these metals are caused by investors using them for hedging, as well as when investors adjust their investments from dollar-denominated financial assets, such as stocks, to dollar-denominated physical assets, like oil and these metals. Rising oil prices also impact the production costs of these metals. Hence, what is the association between oil and metal prices, especially gold? Moreover, the US dollar exchange rate could co-drive both oil and these metal prices, because they are dollar-denominated. Economic theory successfully demonstrates the linkages of these commodity and exchange rate markets. Higher oil prices cause inflation and exchange rate shocks, and thus investors increase their holdings of metal commodities to hedge the risks of inflation and currency fluctuations. Many studies have investigated the co-movement of oil and different metal commodity prices, including Pindyck and Rotenberg (1990), Wahab et al. (1994), Escribano and Granger (1998), Ciner (2001), Sari et al. (2010), Narayan et al. (2010), Chang et al. (2013), Erb and Harvey (2006), Roache and Rossi (2010), Elder et al. (2012), Bouri et al. (2017), etc.

The abovementioned papers examine the co-movement by way of a static concept; in other words, their empirical works are executed based on the assumption of stability in long run relationships. However, since there is a common phenomenon that structural breaks often exist in economic and financial markets, this assumption is not reasonable. In its place, it is more reasonable to consider time-varying and periodic linkages between these commodity markets. Narayan et al. (2010) apply a structural break cointegration test of Gregory and Hansen (1996) to confirm a structural break cointegration between the two markets. Kumar (2017) and Kanjilal and Ghosh (2017) also find evidence of a non-linear relationship between oil and gold prices. Kumar (2017) emphasizes the importance of asymmetric co-movement between the two variable by employing the non-linear ARDL tests. Kanjilal and Ghosh (2017) employs the threshold cointegration to find a non-linear relationship between gold and oil prices.

Allowing for instability or structural breaks between oil and metal prices, Narayan et al. (2010), Kumar (2017), and Kanjilal & Ghosh (2017) estimate their long-run relationships, but they still do not considerr the time-varying process of convergence between these markets, which could be slow and continuing. To fill this gap in the literature, our empirical model examines the dynamic linkages of the prices of three metals and oil from a new angle. The aim of this paper is to investigate the recursive cointegraion among three metal prices (gold, silver, and copper), oil prices, and the US dollar exchange rate. Comparing with the related literature, we present the contributions of this paper below.

First, different from the relative literature, our goal is to track the dynamic and ongoing price linkages of these three metals and oil in the long run and to show the regime-shifting impacts of critical policy changes, economic shocks, and financial crises on these linkages. We apply a two-step examining process to investigate the effects of the time-varying behavior of these linkages. The first part studies the structural-breaking associations of the variables by using the Gregory and Hansen (1996) tests, which can confirm whether there is a structural-breaking cointegration of these variables, and further finds the structural breakpoint of cointegration. For the second part, we conduct recursive cointegration to examine the continuously dynamic process of the cointegrating vectors and parameters of all variables; the results are able to catch the whole structural-breaking trace of short- and long-run relationships of these variables over the full sample period. Based on the results of recursive analysis, we discuss whether the integration among these markets is closer after some economic shocks or financial crises.

Second, the empirical model of this paper specifically includes copper, an important industrial metal, to study the relationship between precious and industrial metals. Unexpected economic growth might decrease gold and silver prices for portfolio rebalancing, while at the same time bringing about higher industrial metal prices due to greater industrial demand. On the other hand, the investment demand for oil and other commodities has greatly increased, because of the development of electronic trading of oil and ETFs in the commodity markets after 2006, and has caused the role of copper, aside from being a pure raw material, to take on a variety of investment options and portfolio diversification strategies. What are the relationships of the precious and industrial metals' prices under this background? Do industrial copper metal prices show a positive or negative linkage with gold prices after the trading role of copper changed? With limited literature analysis on these linkage, this paper thus tries to find the answers to these questions, which will be valuable and usefull for investors and policy-makers.

The remainder of the paper is as follows. Section 2 presents the relative literature. Section 3 offers methodology. Section 4 gives the empirical results. Section 5 concludes.

2. Literature Review

Many papers in the literature have investigated the efficiency hypothesis of commodity markets, with some empirical studies focusing on this issue for industrial metal markets and precious metal markets (Neal, 1989; Beckers, 1984; Wang et al., 2011, etc.). Many relative studies of metal markets look at the volatility-spillover of metal markets, focusing on modeling volatility properties of precious metals, because forecasting volatility is a key factor of asset valuations, hedging, and risk management (Mckenzie et al., 2001; Tully and Lucey, 2007; Hammoudeh and Yuan, 2008; Hammoudeh et al., 2010; Batten et al., 2010; Hammoudeh et al., 2011, etc.).

Some other studies in literature focus on the linkages between metal prices and macroeconomic variables. Many studies have indicated that commodity prices, including metal prices, may be a leading sign of current economic variables since these prices will automatically adjust, being based on continuous auction markets with efficient information (Garner, 1989; Marquis and Cunningham, 1990; Sephton, 1991; Awokuse and Yang, 2002; Hamori, 2007). More recent empirical works support that commodity prices are good indicator variables for macroeconomic variables (De Gregorio et al., 2007; Herrera and Pesavento, 2009; Verheyen, 2010, etc.). Moreover, many papers focus on the linkages between metal prices and inflation or global liquidities (Worthington and Pahlavani, 2007; Belke et al., 2013, etc.).

One important line of empirical works examines the degree of long-run co-movements between oil and metal prices. Pindyck and Rotenberg (1990) are the pioneers on the work of excess co-movement in precious metal prices, and their empirical results show that the excess co-movements of seven major commodities prices are unrelated. Excess co-movement is caused by herding behavior, and while many further studies examine the co-movement of different commodities, most of them focus on the gold and silver markets. The empirical results of Basu and Clouse (1993) confirm significant correlations between the gold spot market price and other market variables, such as equities, bonds, and currencies. Some research studies use cointegration techniques to examine the relationship between metal prices and macroeconomic variables. Wahab et al. (1994) apply the cointegration test and confirm that cointegration exists between gold and silver in both the cash and future markets. Conversely, some other papers display different evidence, such as the results of Escribano and Granger (1998) who find that gold and silver markets are separate after 1990. Ciner (2001) also confirms that the long-run relationship between gold and silver markets is not integrated in the 1990s, because the two markets have different economic usages.

Another important line of empirical works has discussed the impact of oil prices on metal prices. Sari et al. (2010) study the linkages among the prices of four precious metals, oil, and the US dollar exchange rate, and their empirical results support a weak relationship for these variables in the long run, but strong feedbacks in the short run. They also find that there is a temporary and significant impact from an exchange rate shock to precious metal prices. From the viewpoint of price discovery finding out the common effective information between crude oil and gold markets, Zhang and Wei (2010) demonstrate the existence of a cointegrating relationship between the two markets, and that the oil price has a larger contribution according to the common effective price. They also employ the non-linear Granger causality of Baek and Brock (1992) and Hiemstra and Jones (1994), but the results reject non-linear causality and instead confirm linearly unidirectional causality from oil price to gold price. Jain and Ghosh (2013) also support the existence of a cointegration among oil price, precious metal prices, and the Indian Rupee–US Dollar exchange rate. Conversely, the empirical results of Chang et al. (2013) find that the oil price, gold price, and exchange rate are significantly independent of each other.

Expect for the above literature in light of the precious metals, some other research studies have studied the relationship between precious and industrial metals. Erb and Harvey (2006) indicate that economic shocks could cause different reactions among precious and industrial metal prices, because unexpected economic growth might decrease gold and silver prices for rebalancing portfolio actions, while at the same time bringing about increasing industrial metal prices due to higher industrial demand. Roache and Rossi (2010) show a similar result in which an unanticipated economic expansion causes a falling effect on gold and silver prices and then a rising impact on copper prices. Examining the impacts of macroeconomic news announcements on the returns of metal futures, Elder et al. (2012) also confirm that unexpected economic improvement decreases gold and silver prices, but increases copper prices.[1]

The above works investigate co-movement between metal and oil prices by employing linear models. Most of them, except for Zhang and Wei (2010), have not examined structural breaks from exogenous shocks or regime changes. Nevertheless, there is a common phenomenon that structural breaks often exist in economic and financial markets, which lead to non-linearity in the cointegrating relationship. Hence, some papers look into non-linear cointegration between metal and oil prices. Narayan et al. (2010) study the long-run relationship between gold and oil spot and futures markets by applying the structural-breaking cointegration test of Gregory and Hansen (1996), which shows that there is structural-breaking cointegration between the two markets. The empirical result of Kumar (2017) shows that the non-linear structure of

[1] Some papers investigate the volatility behavior between different metal commodity prices (such as Hammoudeh & Yuan, 2008, Behmiri & Manera, 2015, etc.), while others analyze how commodity prices (gold, silver, copper, etc.) respond to macroeconomic news (such as Roache and Rossi, 2010, Elder et al., 2012, etc.), but these papers do not focus on these metals' long-run co-movement.

oil and gold prices causes no cointegration between the two variables, and this work further displays a bidirectional non-linear relationship between the two variables. Comparing with negative shocks, the positive shock of oil price on gold price is more pronounced after employing non-linear ARDL tests. The empirical work of Kanjilal and Ghosh (2017) also supports that the relationship between gold and oil prices is non-linear and asymmetric by employing threshold cointegration, and they indicate that gold is used as a safehaven against inflation only in a typical regime, whereas gold and oil switch back and forth between each other when investors are diversifying their portfolio risk under an extreme regime.

This paper follows this line to investigate the non-linear linkages between oil and metal prices. We apply recursive cointegration in Hansen and Johansen (1993) to examine the continuously dynamic linkages among three metal prices (gold, silver, and copper), oil price, and the US dollar exchange rate. Although some studies listed above estimate the non-linear or structural-breaking long-run relationship between oil and gold prices, they do not consider that the time-varying process of convergence will be slow and continuing. Different with past research, this paper tracks the dynamic and ongoing linkages of the prices of the three metals and oil prices in the long run and catch the whole structural-breaking trace of the short- and long run relationships of these variables over the full sample period.

3. Methodology

3.1 Gregory-Hansen cointegration test with structural break

The sample period of this paper includes some unstable time period, which is caused by some financial and economic shocks on these commodity markets, and then the conventional cointegration tests, such as Johansen cointegration, cannot catch the long run relationship with structural breaks. Hence, we apply the Gregory and Hansen (1996) test (GH test) to examine the long-run relationship among these variables, which can confirm whether there is a structural-breaking cointegration among these variables , and further finds the structural breakpoint of cointegration.[2]

Based on the existence of regime change in the long-run relationship, the GH test is a generalization of the usual residual-based cointegration test. There are three different models of the GH test: model A assumes a level shift, model B assumes a level shift with trend, and model C assumes the slope vector shift. The following equations (1), (2), and (3) express these three models.

$$\text{model A:} \quad y_t = \alpha_1 + \alpha_2 D_t(\tau) + \delta_1 X_t + e_t \qquad (1)$$

[2] Because all of the variables in this paper are non-stationary, it is not an appropriate choice to employ nonlinear models, such as the threshold autoregressive model or the smooth transition autoregressive model, to estimate the relationship with structural break among the variables.

model B: $y_t = \alpha_1 + \alpha_2 D_t(\tau) + \gamma t + \delta_1 X_t + e_t$ (2)

model C: $y_t = \alpha_1 + \alpha_2 D_t(\tau) + \delta_1 X_t + \delta_2 X_t D_t(\tau) + e_t$, (3)

where Y is the dependent variable; X is the independent variable; e_t is the error term, t =1,…,n; D_t is a dummy variable assuming that D_t = 0 if $t \le n\tau$, and D_t = 1 if $t > n\tau$; while $\tau = T_B / n$, T_B is a structural breakpoint. Each τ is estimated to get the residual $\hat{e}_t$, which can be used to calculate the first-order serial correlation coefficient. The subscript t of error term e_t means that the residual sequence is dependent on the choice of breakpoint t.

The examining statistics of the GH cointegration test include three kinds of statistics: the ADF tests of Engle and Granger (1987), and the two tests of Phillips-Quliaris (1990) - the Z_t and Z_α tests. All these three tests are modified under the alternative considered. Because the date of the change is assumed to be unknown, the test statistics are calculated for each breakpoint in the interval of the set T, which is a compact subset (0.15, 0.85). In other words, these tests allow the breakpoint τ to vary over the interval $|0.15T \le \tau \le 0.85T|$, and then the values of $ADF^* = \inf_{\tau \in T} ADF$, $Z_t^* = \inf_{\tau \in T} Z_t$, and $Z_\alpha^* = \inf_{\tau \in T} Z_\alpha$ are calculated - that is, the test statistics are the smallest values of the above statistics across all values of τ ∈ T.

3.2 Recursive cointgegration

To analyze the degree and the sign of relationships among gold prices and the four other variables over different sub-sample periods of the full sample, this paper applies the recursive cointegration of Hansen and Johansen (1993) - a recursive approach to estimate the cointegration tests of Johansen (1988). The model of Johansen tests is shown as the vector autoregressive (VAR) system below.

$$\Delta X_t = \sum_{i=1}^{k-1} \Gamma_i \, \Delta X_{t-i} + \Pi X_{t-1} + \varepsilon_t \quad , \; t = 1, \ldots, N \quad , \quad i = 1, \ldots, m-1 \quad ,$$

$$\Gamma_i = -I + \Pi_1 + \cdots + \Pi_i \quad , \qquad \Pi = -(I - \Pi_1 - \Pi_2 - \cdots - \Pi_k), \qquad (4)$$

where X_t is a vector in log form covering five variables: gold price, silver price, copper price, oil price, and US dollar exchange rate. The symbol Π is the impact matrix, and Π =αβ', where β is the matrix of cointegrating coefficients, and β' X_{t-1} is the cointegrating vector; and α is the matrix of the short-run adjustment coefficients to the cointegrating vector β' X_{t-1}. The null hypothesis is r ≤ n-1, where r is called the rank of the matrix Π, implying that β' X_{t-1} is stationary.

To confirm the number of cointegrating vectors, two test statistics - the trace statistic and the maximum eigenvalue statistic - are used to examine the number of the rank of the matrix ∏ in equation (4). This paper applies the trace statistic, and it is shown as equation (5).

$$\lambda \mathrm{tr}(\gamma) = -N \sum_{i=r+1}^{k} \ln(1 - \hat{\lambda}_i) \quad ,$$

(5)

where $\hat{\lambda}_i$ are the eigenvalues of Π, and N is the number of observations.

Hansen and Johansen (1993) argue that the conventional cointegration tests with structural breaks are based on assuming the fixed long-run coefficient β and attributing its shifts to the short-run coefficient α. They establish two models allowing changes in the long-run coefficient. The first one is the X-representation as in equation (6).

$$\mathrm{Z_{0t}} = \alpha\beta'\mathrm{Z_{1t}} + \gamma\mathrm{Z_{2t}} + \mathrm{e_t}, \tag{6}$$

where $\mathrm{Z_{0t}} = \Delta\mathrm{X_t}$, $\mathrm{Z_{1t}} = \mathrm{X_{t-1}}$, $\mathrm{Z_{2t}} = (\Delta\mathrm{X'}_{\mathrm{t-1}}, \ldots, \Delta\mathrm{X'}_{\mathrm{t-m+1}}, 1)'$, and the assumptions of both coefficients, β and α, are not fixed.

The second model is the R1-representation, and its assumption is only that coefficient β will change, while coefficient α is fixed. The maximum likelihood estimation of this model is on the basis of a reduced-rank regression of Z_{0t} on Z_{1t}, and the residuals R_{0t} and R_{1t} are defined as follows:

$$R_{0t} = Z_{0t} - M_{02}M_{22}^{-1}Z_{2t}$$

$$R_{1t} = Z_{1t} - M_{12}M_{22}^{-1}Z_{2t},$$

where $M_{ij} = \sum_{t=1}^{T} Z_{it}Z'_{jt}$, and the next step is to estimate the regression equation as:

$$R_{0t} = \alpha\beta' R_{1t} + \tilde{e}\text{，} t = 1,2,\ldots,T. \tag{7}$$

The two representations, equations (6) and (7), are used to perform recursive cointegration estimations, including rescursive conitegration rank, recursive long-run parameters β, and recursive short-run parameters α.

4. Empirical Results and Discussions

We set up an empirical model, including oil prices (OIL), the US dollars exchange rate index (EXR), and three metal prices (GOLD, SILVER, and COPPER) to discuss the time-varying behavior of the linkages among the prices of the three metals and oil. The data sample consists of monthly observations from January 1980 to May 2017. The data are sourced from International Financial Statistics (IFS) which is published by the International Monetary Fund (IMF).

4.1 Unit root test results

Before estimating the cointegration vector of the variables, the first step is to examine the stationarity of each variable by unit root tests. The conventional Dickey-Fuller and Phillips-Perron tests have low power against meaningful stationary alternative. By applying GLS detrending yields power gains for unit root tests, Elliot et al., (1996) have shown that the DF-GLS has better finite-sample properties. Hence, we apply the DF-GLS (Elliott et al., 1996) unit root test to examine the stationarity of each variable. The results of the DF-GLS test on Table 1, no matter for the model with or without trend, confirm that all of these five variables follow I(1) processes at the 5% significant level. Furthermore, considering these non-stationary variables with a structural break over the sample period, this paper examines these variables by applying the Perrron (1997) unit root test allowing for a structural break. The results of all three models of Perrron (1997), as seen in Table 1, also confirm these five variables are I(1).

4.2 Gregory and Hansen cointegration tests with structural breaks

Because all of the variables are I(1), the next step is to execute cointegration analysis. Our sample period covers some turbulent times caused by financial and economic innovation. Therefore, it is important to apply the cointegration with structural breaks to analyze the long-run relationship. We apply the Gregory and Hansen (1996) test to examine for structural-breaking cointegration among these five variables in the models. The results of the GH test, based on the equation with gold price as the dependent variable, are shown in Table 2. All the ADF^*, Z_α^*, and Z_t^*

test statistics reject the null hypothesis at the 5% significant level, which means the existence of a cointegration with a structural break among the three metals prices, oil price, and the US dollar exchange rate. Most structural breaks of the cointegration are around 2008 and 2009, because the 2008-2009 global financial crisis depressed economic activity and oil prices, but raised gold prices as a form of hedge.

4.3 Recursive cointegration test

The GH structural-breaking cointegration test cannot continuously trace structural breakpoints of cointegration as time passes in the long run. Hence, we employ recursive cointegration to examine the continuously dynamic convergence of the three metals' prices, oil price, and the US dollar exchange rate, conducting the recursive cointegration analysis of Hansen and Johansen (1993) to test for the stability of the cointegrating rank and parameters. The trace statistics of the recursive cointegration test are estimated using 72 observations at first and by adding one observation to the end as time passes. The results of recursive trace statistics are shown as a continuous graph of trace test statistics, which can present the dynamics of the number of cointegrating vectors.

Figure 1 displays the scaled trace statistics for the null hypotheses $r \leq i, i = 0,1,2,3,4$. If the value of the recursive trace statistics is over one at the 5% critical value, then the corresponding null hypothesis of $r \leq i, i = 0,1,2,3,4$ can be rejected at the 5% significant level. In Figure 1, the first line is over the 5% critical value after 1995, which means that the five non-stationary variables are related by one cointegration vector after 1995. The second line is also over the 5% critical value from 2010 to 2012, implying the 2010-2012 European sovereign debt crisis caused further closer linkages among these five markets. Generally, our results show at least one significant and strong long-run equilibrium among the three metals' prices, oil price, and the US dollar exchange rate after 1995. There are similar results in the past literature; for example, Narayan et al. (2010) confirm that there is cointegration between gold and oil markets, and Sari et al. (2010) find a cointegration among the prices of four precious metals, oil price, and the US dollar exchange rate, even though it is weak.

We next estimate the coefficients of the cointegrating vector, β, to discuss how gold price and the other four variables are related in the long run. The recursive cointegrating coefficient of each variable, β, is normalized around the dependent variable, gold price, and shown as Figures 2(a), 2(b), 2(c), and 2(d) at the 95% confidence level. The recursive cointegrating coefficient, β, of silver price is positive for the full sample period and is significantly different from zero before 2009. Gold and silver are precious metals, and both generally show a close linkage with each other. The cointegrating coefficient of silver prices exhibits a substantial increase over much of the period after 2009, implying a larger positive effect from silver prices on gold prices after the 2008-2009 global financial crisis.

There is a special phenomenon in Figure 2(a), whereby the coefficient turns insignificant [3] in some periods after 2009, dispalying that the cointegrating relationship between gold and silver markets is unstable after the 2008-2009 global financial crisis. There are several economic incidents after 2009, including the European sovereign debt crisis, and Brexit.[4] These economic shocks increased the risk of investments and caused unstable flows of funds among different financial and commodity markets, which also led to the unstable long-run relationship between gold and silver prices after 2009. In short, the impact of silver prices on gold prices was positive and significant before 2009, and this linkage became unstable after 2009 due to several economic incidents.

In Figure 2(b) the recursive cointegrating coefficient, β, of copper price is significantly positive over much of the full sample period. Although some empirical works show gold and copper react differently to economic shocks (Erb and Harvey, 2006; Roache and Rossi, 2010; Elder et al. 2012), our empirical result in Figure 2(b)

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[3] If the 95% confidence interval (the interval between two dash lines) of recursive coefficient β covers the value of zero, then β is insignificantly different from zero. Conversely, if the 95% confidence interval does not cover the value of zero, then β is significantly different from zero.

[4] In June 2016, the United Kingdom voted to leave the European Union.

supports the positive linkage between gold and copper prices over much of the sample period. This coefficient became smaller after 2009, because of the 2008-2009 global financial crisis. After 2012, it continuously decreases and turns insignificant over much of the period, which is caused by the demand for copper significantly decreasing, because the economic growth rate in China, the world's biggest user of copper, dramatically dropped after 2011. Put briefly, the 2008-2009 global financial crisis decreased the positive linkage between gold and copper prices, and the falling economic growth rate in China caused lower demand for copper, thus further leading to a structural break in correlation between gold and copper prices after 2012.

The recursive cointegrating coefficient, β, of oil price, in Figure 2(c) shows that the impact of oil prices on gold prices is ambiguous. This coefficient is negative before 2003 (except for 1986), and the sign of the coefficient becomes uncertain after 2003 due to increasing speculative demand of crude oil in advance of the 2003 Iraq War. Oil and gold are the two most importantly traded commodities, and the relationship between them is positive or negative, depending on investors switching between gold and oil or combining them to diversify their portfolios. In Figure 2(c) the recursive coefficient of oil prices presents different signs, because of dissimilar strategies in investors' portfolios over different periods. The empirical work of Kanjilal and Ghosh (2017) shows similar results, finding that the relationship between gold and oil prices is different in different regimes. Moreover, the coefficient of oil prices is insignificantly different from zero after 1991. Gold prices are generally less volatile, whereas oil prices frequently change, because they rapidly respond rapidly to different geopolitical and economic shocks. In light of the past literature, Soytas et al. (2009) also indicate the insignificant explanatory power of oil prices on gold prices.

As to the recursive cointegrating coefficient, β, of the US dollar exchange rate, in Figure 2(d) it is, as expected, negative over the whole period, displaying lower gold prices under US dollar appreciation. This coefficient is insignificant before 1998, but then significant after 1998, likely affected by the advent of the Euro on January 1999, because important exchange rate regime changes usually significantly impact the behavour of commodity prices.

Finally, the recursive cointegrating coefficients, β, of silver and copper, as Figures 2(a) and 2(b), decrease after 2003,[5] showing that the impacting powers from silver and copper prices on gold price becomes smaller after 2003, which is related in the development of ccommodity ETFs. The first gold ETF was launched in 2003 on the Australian Stock Exchange, and the gold ETF trading began on the New York Stock Exchange (NYSE) in 2004. Afterwards, ETFs across all commodity markets are in 2006, causing a new stage of investment diversification strategies since 2006

[5] The decreasing trend of β is changed around 2008 because of the impacts from the 2008-2009 global financial crisis.

(Kanjilala and Ghosh, 2017).

4.4 The recursive adjustment coefficients and the weak exogeneity test

To discuss the short-run dynamic adjustment of each market, we estimate the recursive adjustment coefficient of the error correction term, α, for these five variables, as in Figures 3(a) to 3(e). The findings from these figures also can be used to judge weak exogeneity of the variables in a cointegrated system. If the recursive adjustment coefficient of one variable is insignificant from zero, α = 0, then there is weak exogeneity of this variable in a cointegrated system. Hall and Milne (1994) indicate that weak exogeneity in a cointegrated system is equivalent to the notion of long-run non-causality, which implies restrictions on the adjustment coefficient metrix of the error correction term, metrix α. Hereafter, some empirical works have examined the weak exogeneity tests to analyze long-run causality (including Aruga and Managi, 2011; Herzer et al., 2015, etc.). Figures 3(a) to 3(e) offer a number of important findings as we note below.

First, the recursive adjustment coefficients α of the three metals' prices, as in Figures 3(a), 3(b), and 3(c), are negative over much of the period, showing that the three metal markets are stable, because their prices converge to a long-run equilibrium. However, the speeds of convergence to the long-run equilibrium are slower for the three metal markets after 2009, because the magnitudes of the adjustment coefficient, α, turn smaller as time passes, especially after 2009.

Second, the recursive adjustment coefficients of oil prices and the US dollar exchange rate, in Figures 3(d) and 3(e), are positive over much of the period, meaning that the error-correction mechanism does not push these two markets toward a long-run equilibrium after a shock. Hence, the adjustment of this cointegration depends on the three metal markets instead of the oil and US dollar exchange rate markets.

Third and finally, the recursive adjustment coefficients α of gold and oil prices, as illustrated in Figures 3(a) and 3(d), are insignificantly different from zero over the whole period[6] - that is, gold and oil prices are weakly exogenous over the whole period. Conversely, the recursive adjustment coefficients α of silver prices and the US dollar exchange rate, in Figures 3(b) and 3(e), are significantly different from zero after 1990, thus rejecting the hypothesis of weak exogeneity for the two after 1990. Because the long-run causality is tested under the weak exogeneity test, gold and oil prices are weakly exogenous, but silver prices and the US dollar exchange rate are not, meaning that the former two have a long-run unidirectional causality on the latter two

[6] The significance of recursive coefficient α can be judged by applying the same rule as recursive coefficient β (see note 2).

over much of the period. Moreover, there is no long-run causality between gold and oil prices. In other words, gold and oil markets are weakly exogenous to the silver and US dollar exchange rate markets.

It is worth noting that the 2008-2009 global financial crisis led to a structural change in the long-run causality of copper prices. Figure 3(c) displays there is no weak exogeneity for copper prices over much of the period before 2009, but weak exogeneity of copper prices exists after 2009. Therefore, gold and oil prices led copper prices in a long-run relationship over much of the period before 2009. After 2009, there is no long-run causality between copper and gold prices, and neither is there one between copper and oil prices.

In light of the long-run causalities of the three metal markets, the long-run causality among gold and silver prices remains consistent during the two periods of before or after the 2008-2009 global financial crisis. However, the long-run causality between gold prices and industrial copper prices shows a structural break around 2009 due to the 2008-2009 global financial crisis.

5. Conclusions

The aim of this paper is to study the continuously time-varying relationships among three metal prices, oil prices, and the US dollar exchange rate. To test the implications of the time-varying behavior of the relationship among these five markets, we apply the recursive cointegration of Hansen and Johansen (1993) to trace the dynamic linkages. The sample covers monthly data over the period from January 1980 to May 2017. We present the empirical evidence as follows.

First, the results of the recursive trace statistics display one significant and strong cointegration among the three metal prices, oil prices, and the US dollar exchange rate over much of the period after 1995. Moreover, the European sovereign debt crisis caused a closer linkage of these five markets from 2010 to 2012.

Second, no matter for silver or copper prices, both have a positive long-run linkage with gold price over much of the sample period, but the structural breaks of the two linkages appear during different periods. The development of ccommodity ETFs causes smaller impacting powers from silver and copper prices on gold price after 2003. The linkage between silver and gold prices turns insignificant over much of the period after 2009, because of several economic incidents, but the linkage between gold and copper prices is insignificant from the impact of a substantial decrease in copper demand from China after 2012.

Third, the long-run relationship between oil and gold prices is inversely related before 2003 and turns uncertain after 2003, mainly caused by the 2003 Iraq War. The appreciation of the US dollar has dropped gold prices in the long run, and the relationship becomes significant after the advent of the Euro on January 1999.

Fourth and finally, there is no long-run causality between gold and oil prices. As to the long-run causality among the three metal prices, gold prices lead silver and copper prices over much of the sample period, but the long-run causality between gold and copper prices turns insignificant after the 2008-2009 global financial crisis.

From the empirical results of this paper, there are some suggestions as to the following. First, the empirical results of this paper present that long-run integration among gold and the other four markets does exist, and the linkage is very strong even when affected by many economic shocks or other crises. Nevertheless, integration among gold and the other four markets can bring about a broader and more diversified pool for investors who can benefit from the information content of the long-run equilibrium and build profitable strategies based on such information.

Second, the long-run linkage between oil and gold prices is ambiguous and insignificant for much of the time period, and the direction of this linkage more frequently changes after the 2008-2009 global financial crisis, bringing about a higher risk of holding gold and oil commodities when performing portfolio diversification. Investors and portfolio managers should thus more cautiously control their portfolios' risk of holding oil and gold at the same time.

Third, rising gold prices increase silver and copper prices in the long run and are also a long-run leading indicator of the two. Hence, investors can use gold prices as a leading signal to adjust the holding positions of the latter two metal commodities and rebalance their portfolio diversification. For producers and policymakers, because of this leading signal from the change in gold prices, they can adopt some precautionary measures to prevent unfavorable impacts of rising metal prices on production cost and inflation. It is noteworthy that the function of gold prices as a leading signal becomes unstable and weaker after the 2008-2009 global financial crisis. Hence, one should be careful to track and watch whether or not gold prices can still be a good leading signal in the future.

Finally, the long-run relationship between gold price and the US dollar is inversely related, implying investor could get profits from higher gold price but take loss of depreciating the US dollar. Hence, in countries other than the US, investors and portfolio managers should take some hedging strategies against the exchange rate risk when they invest gold and other metal commodities, and policymakers, especially in developing countries with fragile economic and financial systems, should adopt some macroprudential policies to avoid disadvantageous shocks of exchange rate fluctuations on international trade and capital flows.

As to the future research, the aim of this paper is to examine the dynamic linkages among gold and other commodity markets, and the relationships between commodity and financial markets are not focused on; in the future, the development of ccommodity ETFs will cause closer linkages between commodity markets and financial markets, so future study can examine the dynamic impacts from financial markets, such as stock and bond markets, on commodity markets as ccommodity ETFs rise. Moreover, future works aslo can focus on how the trading volumes of commodity ETFs affect time-varying volatility spillover effects between gold and other commodity markets.

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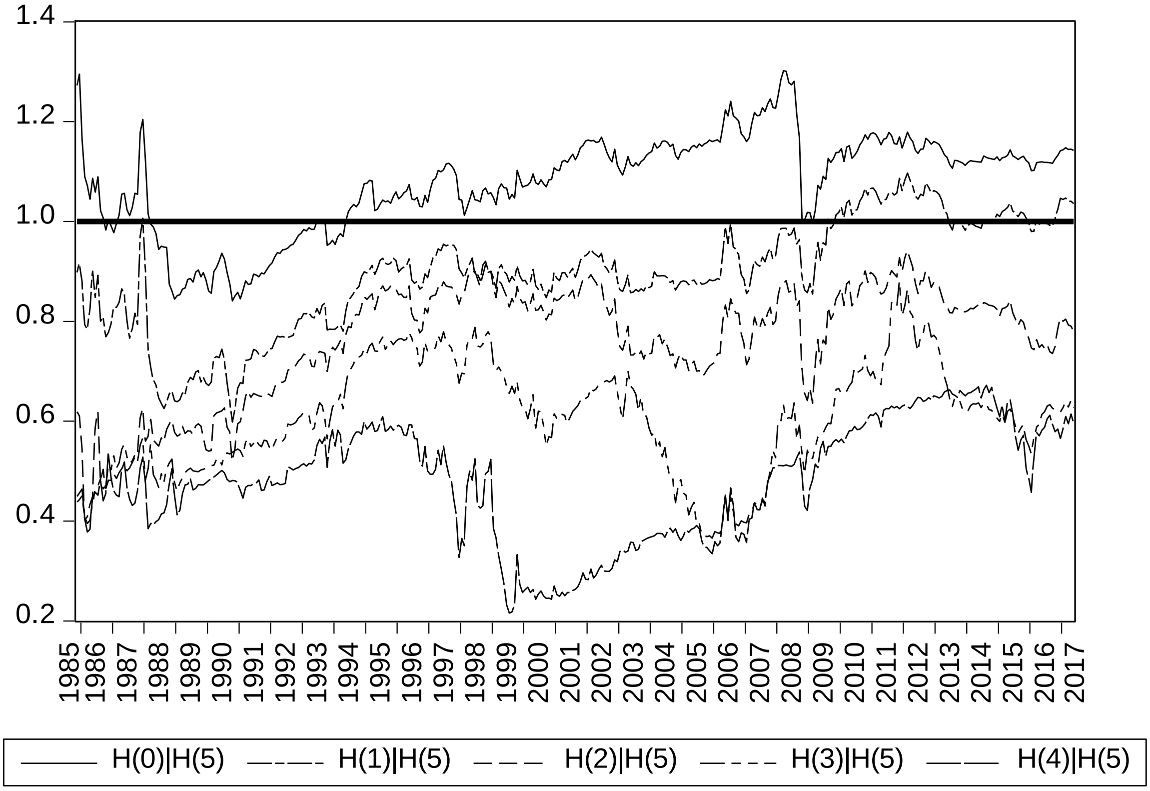

Figure 1. Recursive standardized trace test

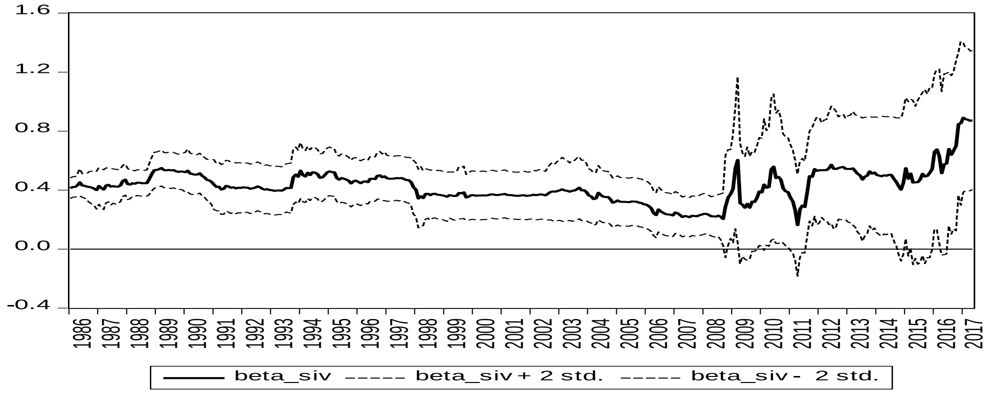

Figure 2(a). The recursive cointegrating coefficient β of silver prices

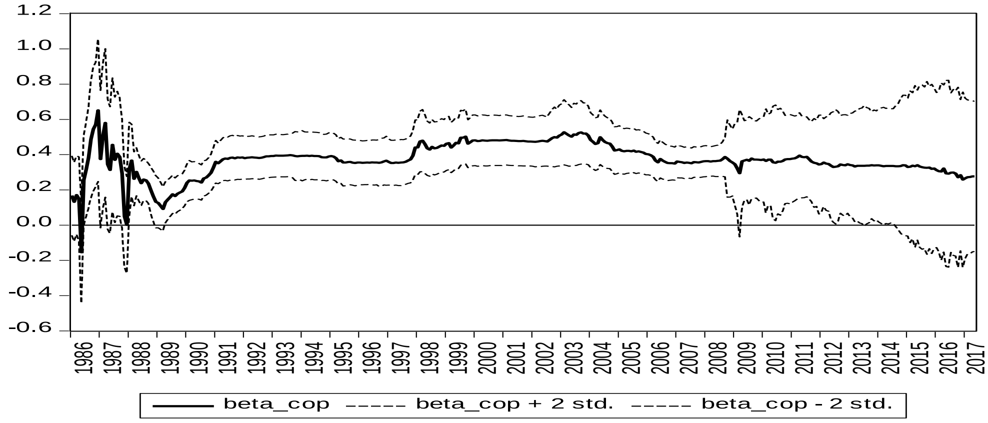

Figure 2(b). The recursive cointegrating coefficient β of copper prices

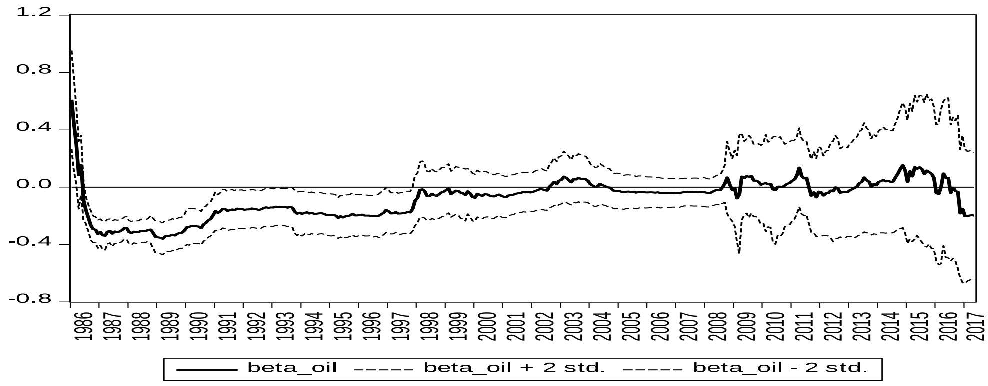

Figure 2(c). The recursive cointegrating coefficient β of oil prices

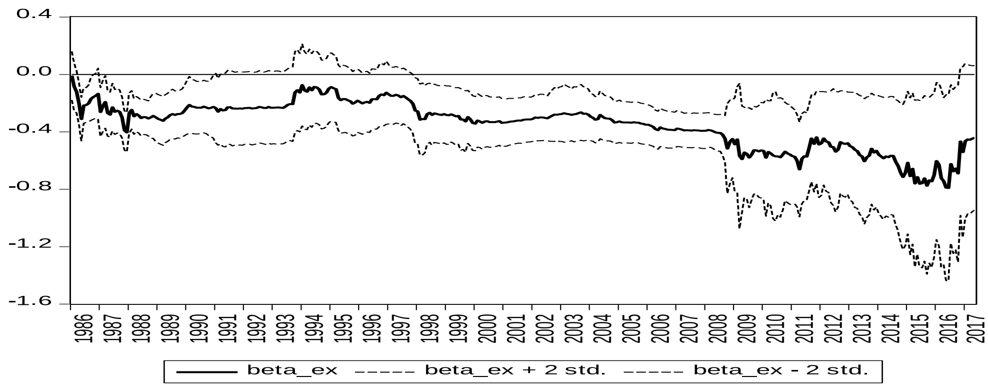

Figure 2(d). The recursive cointegrating coefficient β of US$ exchange rate

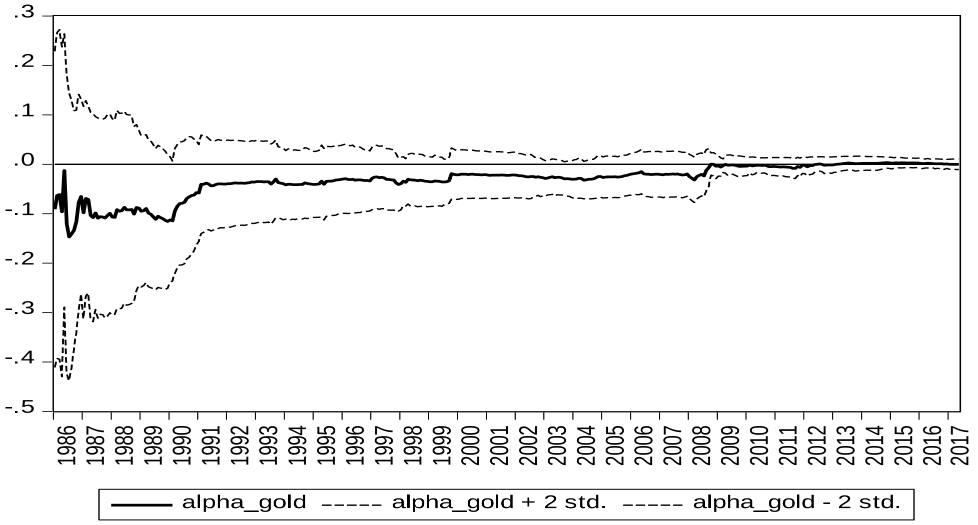

Figure 3(a). The recursive adjustment coefficient α of gold prices

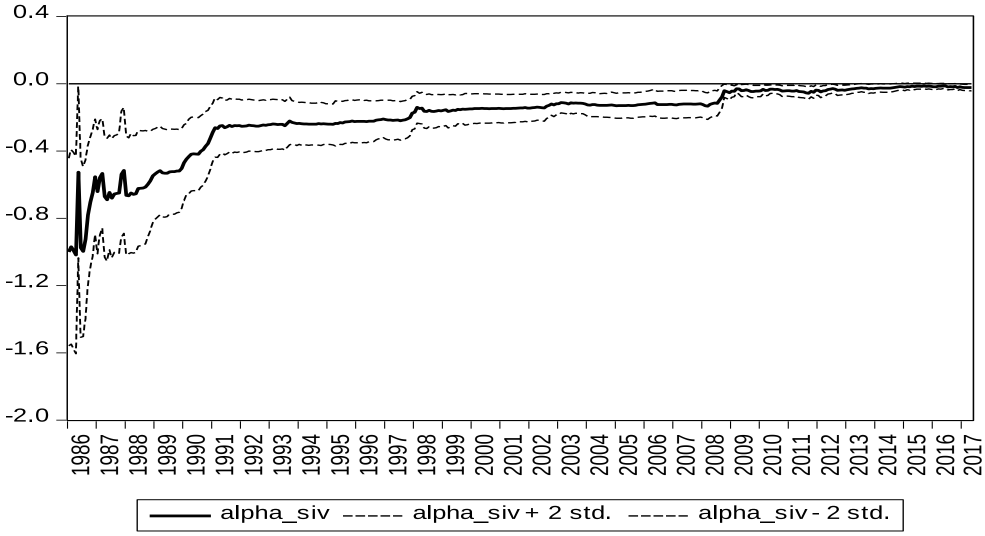

Figure 3(b). The recursive adjustment coefficient α of silver prices

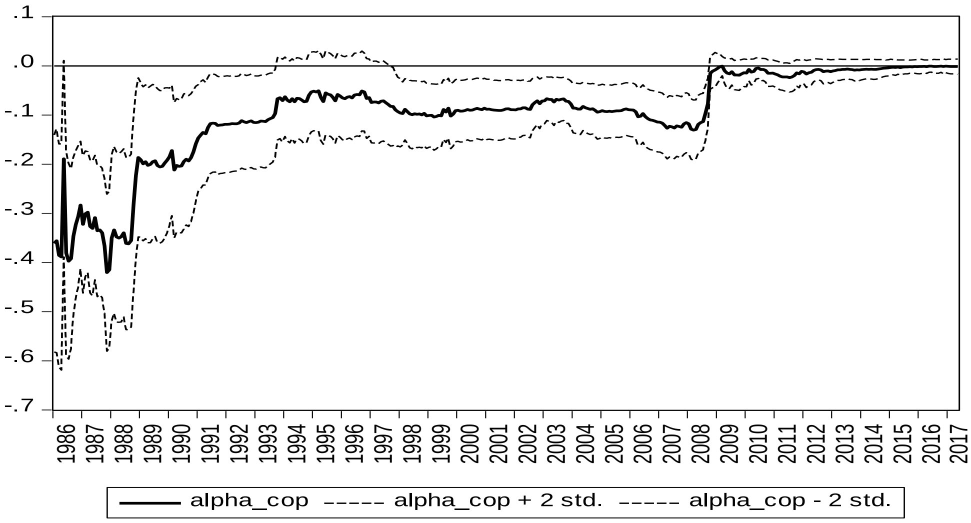

Figure 3(c). The recursive adjustment coefficient α of copper prices

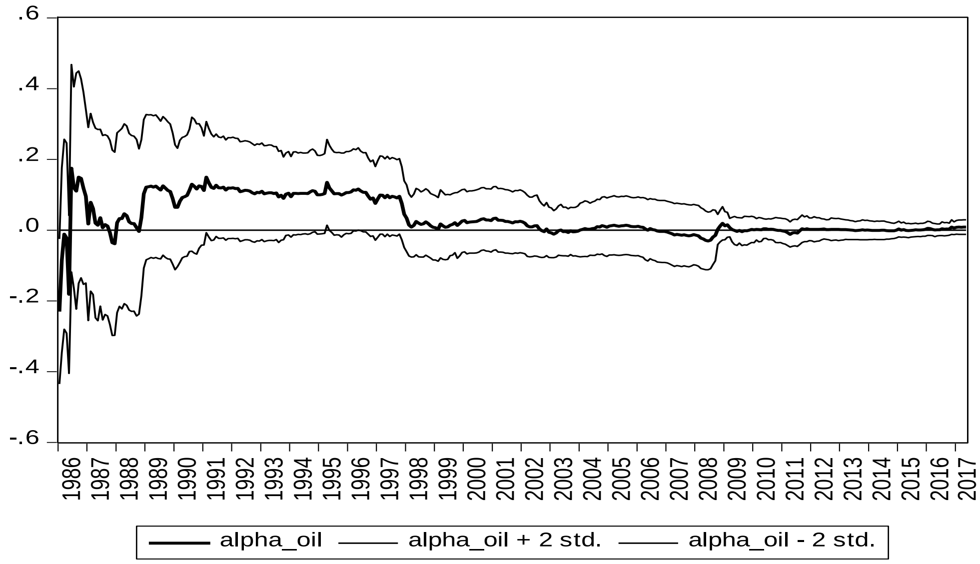

Figure 3(d). The recursive adjustment coefficient α of oil prices

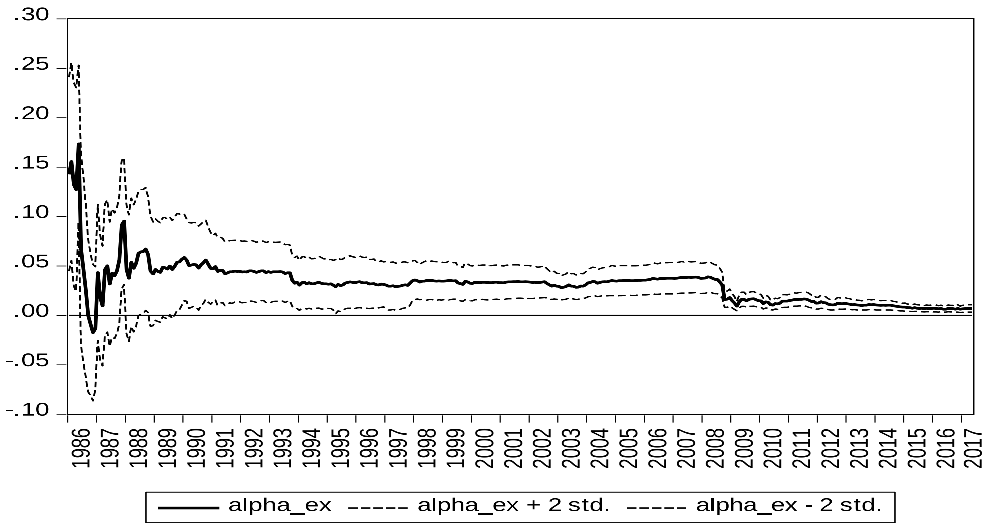

Figure 3(e). The recursive adjustment coefficient α of the USD exchange rate

Table 1 Results of unit root tests

	DF-GLS		Perron (1997)		
	Without trend	With trend	A	B	C
levels					
OIL	-1.8268*	-1.9825	-4.2420	-3.3233	-3.9161
	(1)	(1)	[2003M9]	[1990M11]	[2003M9]
EXR	1.2034	-0.5291	-3.7531	-2.5176	-3.1043
	(1)	(1)	[2002M10]	[1997M10]	[2002M10]
GOLD	-0.5065	-0.6427	-4.3604	-2.0552	-3.3197
	(1)	(1)	[2005M7]	[1999M12]	[2005M08]
SILVER	-0.5232	-0.6505	-4.6118	-2.3236	-3.9893
	(2)	(2)	[2005M9]	[1994M3]	[2005M9]
COPPER	-1.3226	-1.9095	-4.6206	-2.7099	-4.3750
	(1)	(1)	[2003M9]	[2000M1]	[2005M5]
First differences					
DOIL	-14.8621***	-15.1274***	-11.0703***	-10.8416***	-11.1365***
	(0)	(0)	[2008M10]	[2005M8]	[1986M7]
DEXR	-12.6799***	-14.2078***	-14.8766***	-14.5232***	-15.0399***
	(0)	(0)	[2008M10]	[2007M6]	[2008M10]
DGOLD	-16.8910***	-18.3985***	-19.1510***	-18.8565***	-18.8565***
	(0)	(0)	[2011M8]	[2009M11]	[2009M11]
DSILVER	-4.6087***	9.4548***	-17.1008***	-16.8434***	-17.1019***
	(3)	(2)	[2011M4]	[1985M8]	[2011M4]
DCOPPER	-2.5935**	-4.6347***	-17.1008***	-16.8434***	-17.1019***
	(4)	(4)	[2011M04]	[1985M8]	[2011M4]

Notes: 1) *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The numbers in parentheses are the lag order in the DF-GLS tests. The numbers in brackets of the Perron (1997) tests are the estimated structural break dates.
2) Model A of Perron (1997) allows for a change in the level of the series, model B allows for a change in the slope of the trend of a series, while model C combines both changes in the level and the slope of the trend.

Table 2 Gregory-Hansen cointegration tests

Test statistic	A	B	C
ADF^*	-6.0047** [2008M2]	-6.0940*** [2008M2]	-6.3197*** [2009M1]
Z_a^*	-60.0671** [2008M4]	-60.0365** [2008M04]	-63.9453** [2009M2]
Z_t^*	-5.6658** [2008M4]	-7.9352*** [1997M07]	-5.8686** [2009M2]

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Models A, B, and C are the three model types of Gregory and Hansen (1996). The critical values are from Table 1 of Gregory and Hansen (1996). The numbers in brackets are the estimated structural break dates.